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(54) **METHOD FOR MAKING THIN FILM TRANSISTOR**

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See application file for complete search history.

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Primary Examiner — Jami M Valentine

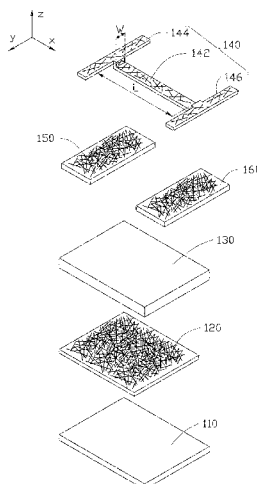
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ABSTRACT

A thin film transistor is provided. The thin film transistor includes a source electrode, a drain electrode, a semiconductor layer, an insulating layer and a gate electrode. The drain electrode is spaced from the source electrode. The semiconductor layer is electrically connected to the source electrode and the drain electrode. The gate electrode is insulated with the source electrode, the drain electrode and the semiconductor layer by the insulating layer. The gate electrode, the source electrode, and the drain electrode comprise a plurality of first carbon nanotubes. The semiconductor layer comprises a plurality of second carbon nanotubes. A distribution density of the plurality of first carbon nanotubes is about 20 times as much as that of the plurality of second carbon nanotubes. A number of the plurality of second carbon nanotubes in 1 square micrometers is smaller than or equal to 1.

14 Claims, 8 Drawing Sheets



- (51) **Int. Cl.**
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- (52) **U.S. Cl.**
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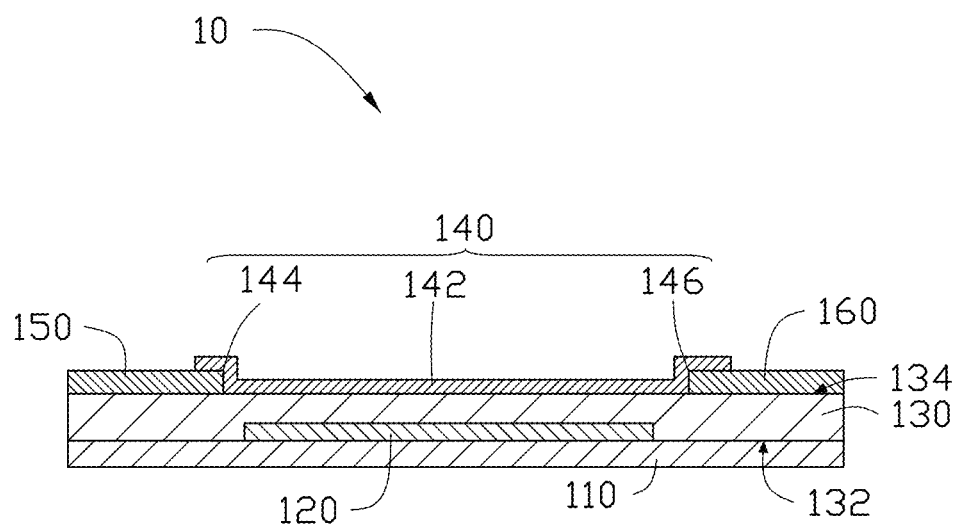


FIG. 1

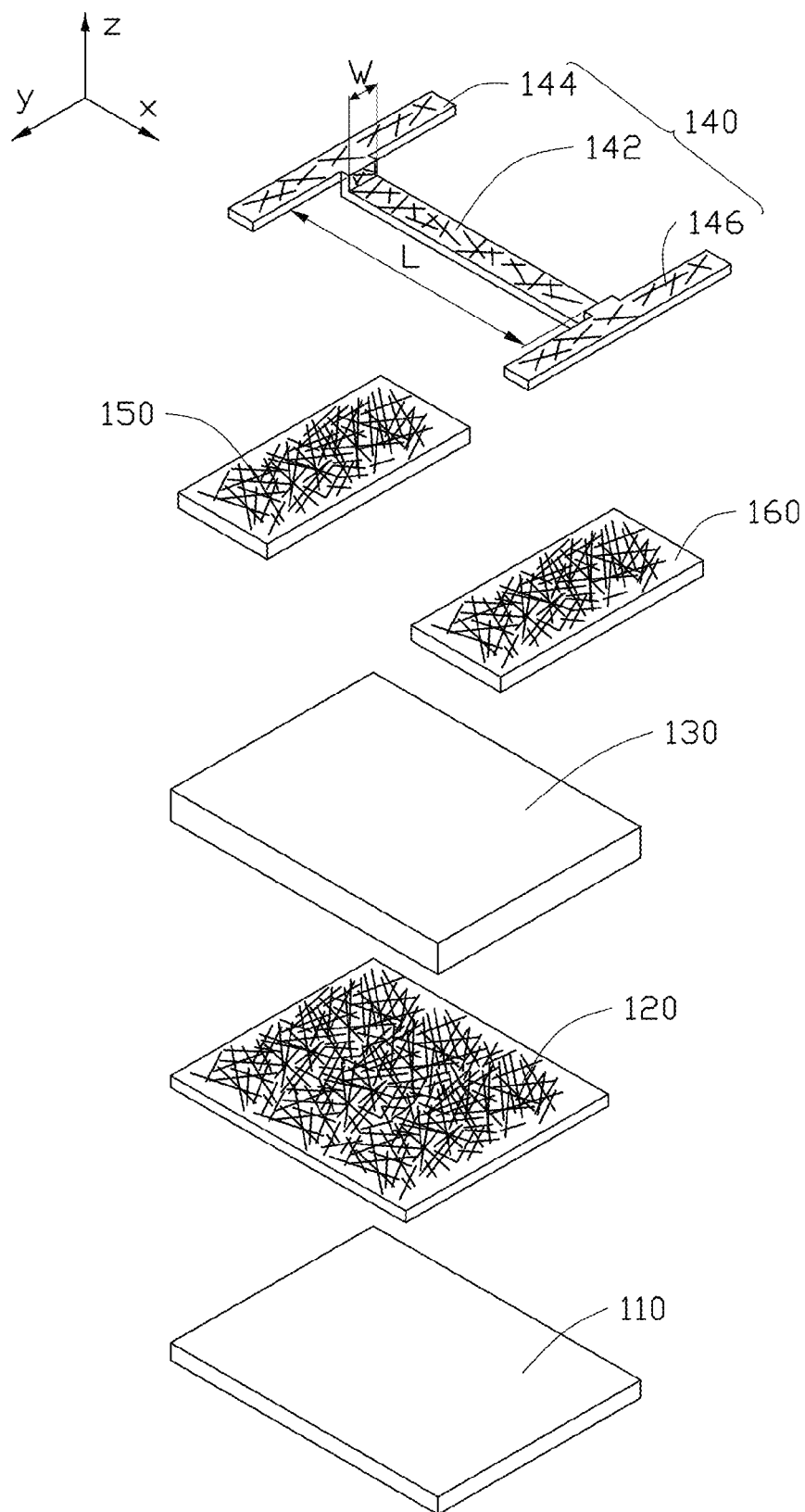


FIG. 2

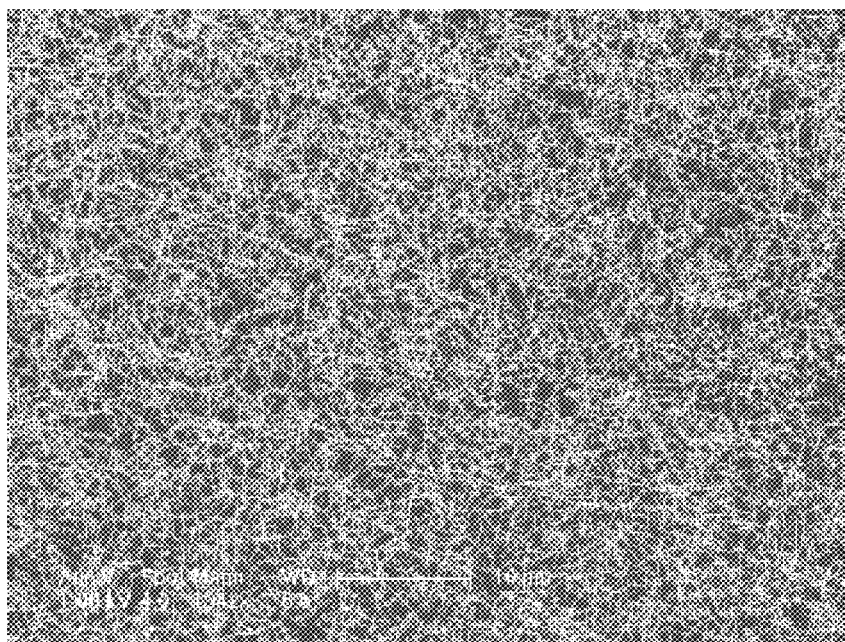


FIG. 3

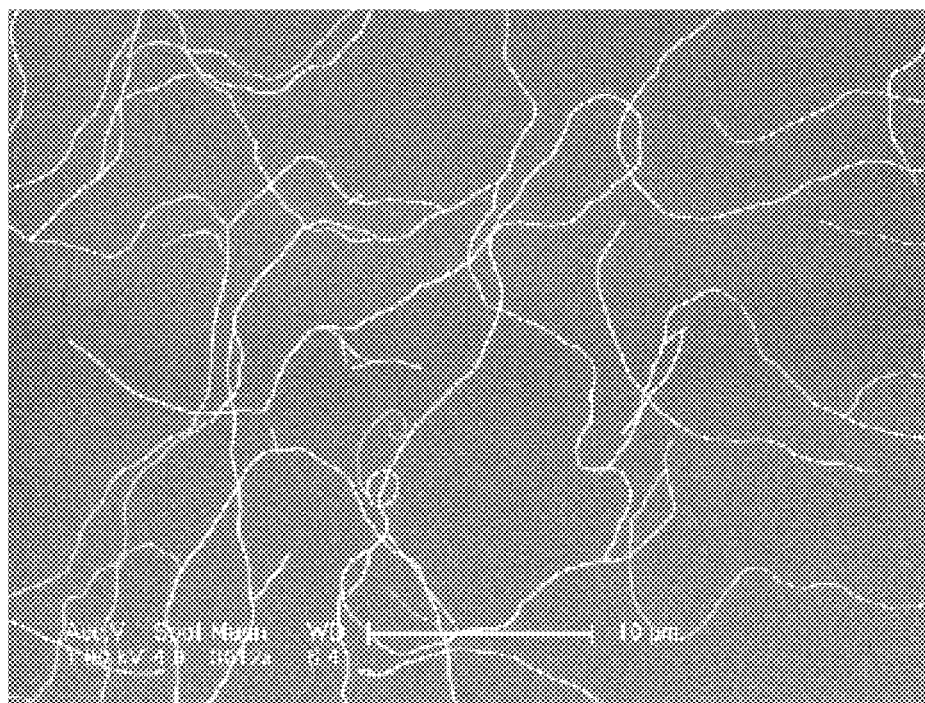


FIG. 4

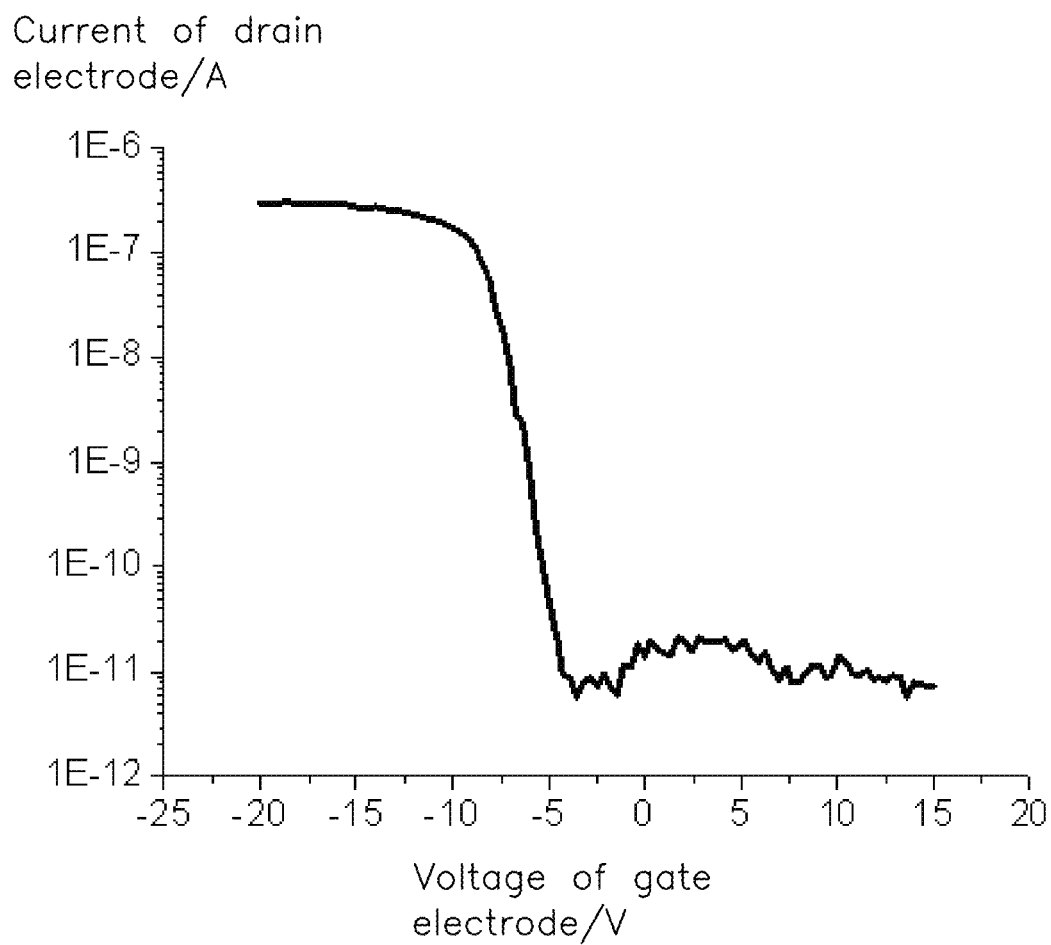


FIG. 5

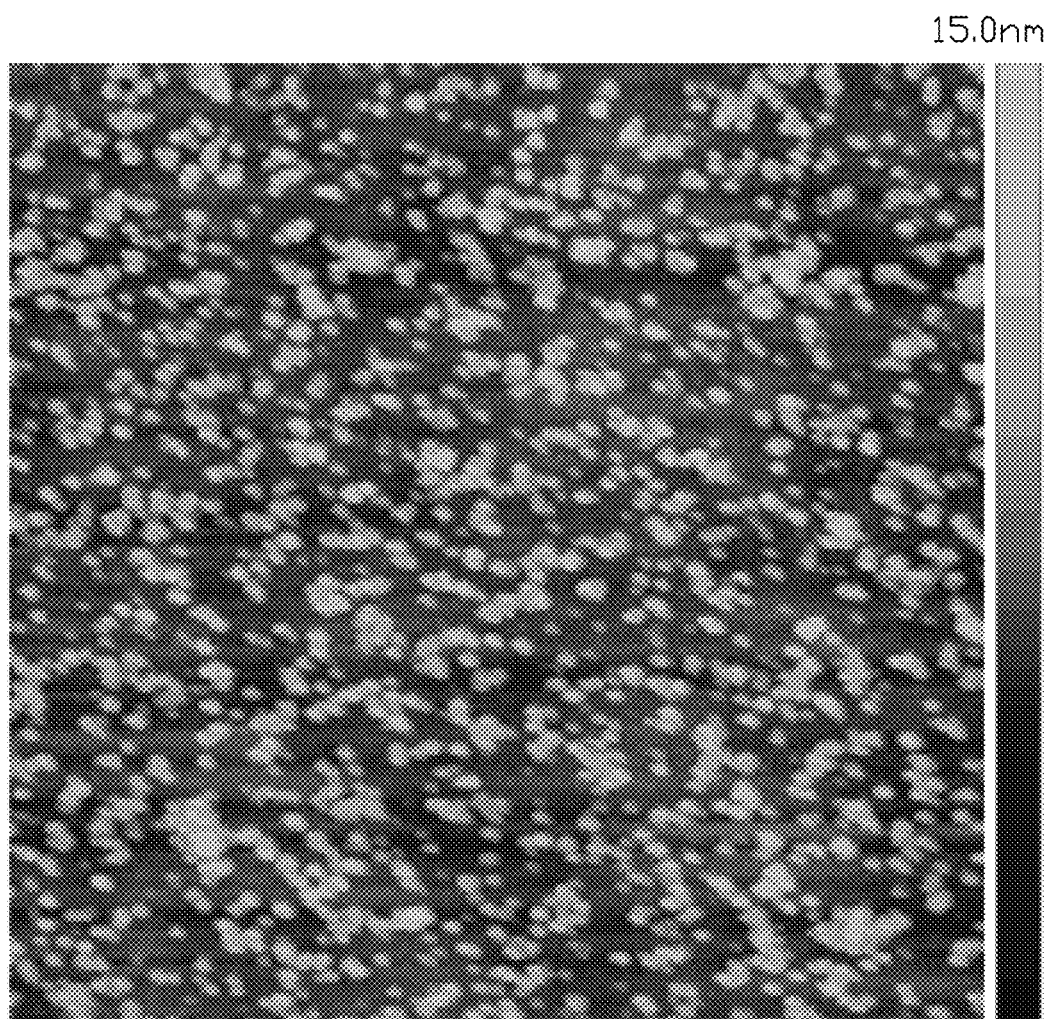


FIG. 6

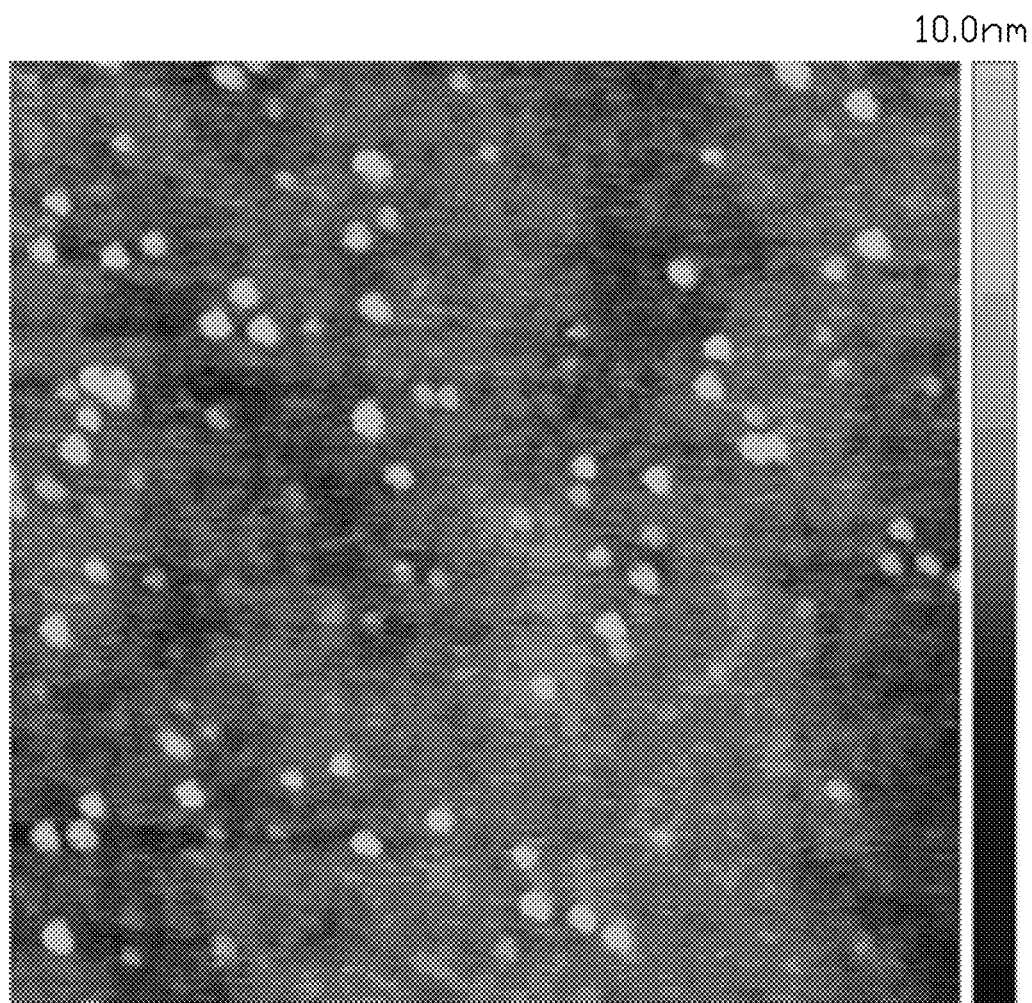


FIG. 7

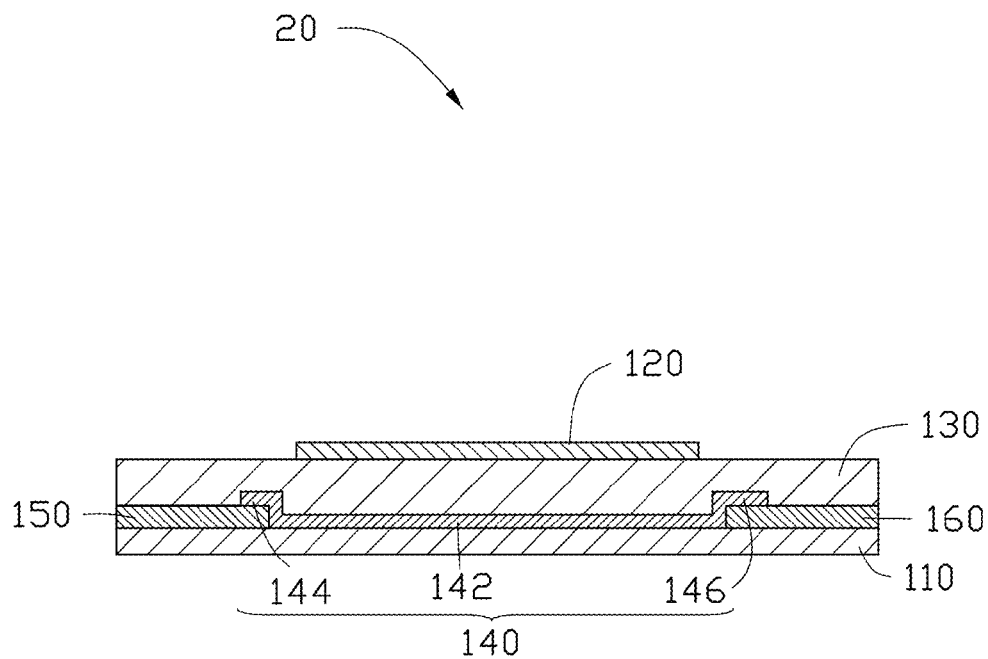


FIG. 8

METHOD FOR MAKING THIN FILM TRANSISTOR

RELATED APPLICATIONS

This application is a continuation application of U.S. patent application Ser. No. 14/139,966, filed on Dec. 24, 2013, entitled, "THIN FILM TRANSISTOR AND METHOD FOR MAKING THE SAME", which claims all benefits accruing under 35 U.S.C. §119 from China Patent Application No. 201310130609.6, filed on Apr. 16, 2013 in the China Intellectual Property Office, the contents of which are hereby incorporated by reference. The disclosures of the above-identified applications are incorporated herein by reference.

BACKGROUND

1. Technical Field

The present invention relates to thin film transistors and, particularly, to a carbon nanotube based thin film transistor.

2. Discussion of Related Art

A typical thin film transistor (TFT) is made of a substrate, a gate electrode, an insulation layer, a drain electrode, a source electrode, and a semiconductor layer. The thin film transistor performs a switching operation by modulating an amount of carriers accumulated in an interface between the insulation layer and the semiconductor layer from an accumulation state to a depletion state, with applied voltage to the gate electrode, to change an amount of the current passing between the drain electrode and the source electrode.

Material of semiconductor layer is semiconductive material and materials of source electrode and drain electrode are metal materials. Because materials of source electrode and drain electrode are different from material of semiconductor layer, interface barrier existed between the semiconductor layer and the source electrode or the drain electrode has an adversely effect to the property of thin film transistor. Furthermore, the thickness of the semiconductor layer, the source electrode and the drain electrode is relatively large which affects the light transmittance of the thin film transistor.

What is needed, therefore, is a thin film transistor that can overcome the above-described shortcomings.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the embodiments can be better understood with references to the following drawings. The components in the drawings are not necessarily drawn to scale, the emphasis instead being placed upon clearly illustrating the principles of the embodiments. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. 1 is a cross sectional view of one embodiment of a thin film transistor.

FIG. 2 is a schematic structural view of the thin film transistor of FIG. 1.

FIG. 3 is a Scanning Electron Microscope (SEM) image of a first carbon nanotube layer.

FIG. 4 is an SEM image of a second carbon nanotube layer.

FIG. 5 is a test paragraph of on/off ratio of current of the thin film transistor of FIG. 1.

FIG. 6 is an Atomic Force Microscope (AFM) image of a first substrate deposited catalyst for growing the first carbon nanotube layer.

FIG. 7 is an AFM image of a second substrate deposited catalyst for growing the second carbon nanotube layer.

FIG. 8 is a cross sectional view of another embodiment of a thin film transistor.

DETAILED DESCRIPTION

The disclosure is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to "an" or "one" embodiment in this disclosure are not necessarily to the same embodiment, and such references mean at least one.

Referring to FIG. 1 and FIG. 2, a thin film transistor 10 of one embodiment includes a gate electrode 120, an insulating layer 130, a semiconductor layer 140, a source electrode 150, and a drain electrode 160. The insulating layer 130 has a first surface 132 and a second surface 134 opposite to the first surface 132. The gate electrode 120 is located on the first surface 132. The semiconductor layer 140, the source electrode 150, and the drain electrode 160 are located on the second surface 134. The thin film transistor 10 is positioned on a surface of an insulating substrate 110.

The source electrode 150 and the drain electrode 160 are spaced from each other. The semiconductor layer 140 is electrically connected to the source electrode 150 and the drain electrode 160. The gate electrode 120 is insulated from the semiconductor layer 140, the source electrode 150, and the drain electrode 160 through the insulating layer 130.

The thin film transistor 10 can be a bottom gate structure. In detail, the gate electrode 120 is located on the insulating substrate 110. The insulating layer 130 covers the gate electrode 120, and a part of the insulating layer 130 is directly located on the insulating substrate 110. The semiconductor layer 140 is located between and extends onto the source electrode 150 and the drain electrode 160. A part of the semiconductor layer 140 between the source electrode 150 and the drain electrode 160 is defined as a middle part 142. The middle part 142 is defined as a channel. A part of the semiconductor layer 140 overlapped with the source electrode 150 is defined as a first connecting part 144. A part of the semiconductor layer 140 overlapped with the drain electrode 160 is defined as a second connecting part 146. In one embodiment, the first connecting part 144 is located on and in contact with a surface of the source electrode 150 away from the insulating layer 130, and the second connecting part 146 is located on and in contact with a surface of the drain electrode 160 away from the insulating layer 130.

The insulating substrate 110 is provided for supporting the thin film transistors 10. The material of the insulating substrate 110 can be rigid materials, such as glass, crystal, ceramic, diamond, and silicon, or flexible materials such as plastic or resin. In detail, the flexible material can be polycarbonate (PC), polymethyl methacrylate acrylic (PMMA), polyethylene terephthalate (PET), polyethersulfone (PES), cellulose ester, polyvinyl chloride (PVC), benzocyclobutenes (BCB), acrylic resins, acrylonitrile butadiene styrene (ABS), polyamide (PA), or combination thereof. In one embodiment, the material of the insulating substrate is PET. The shape and size of the insulating substrate 110 are arbitrary.

The gate electrode 120, the source electrode 150, and the drain electrode 160 can include a first carbon nanotube layer. Referring to FIG. 3, the first carbon nanotube layer includes a plurality of first carbon nanotubes joined by van der Waals attractive force. The plurality of first carbon nanotubes is single-walled carbon nanotubes and arranged disordered. The term 'disordered' is defined as the plurality of first carbon nanotubes is arranged along many different directions, and the aligning directions of the plurality of first carbon nano-

tubes are random. The plurality of first carbon nanotubes arranged along each different direction can be almost the same (e.g. uniformly disordered). The disordered first carbon nanotubes can be isotropic. The disordered first carbon nanotubes entangle with each other to form the first carbon nanotube layer, and a plurality of apertures is defined by the plurality of first carbon nanotubes. A diameter of the aperture can smaller than 50 micrometers. The plurality of the apertures can enhance the light transprence of the first carbon nanotube layer.

The plurality of first carbon nanotubes is substantially parallel with a surface of the first carbon nanotube layer. The plurality of first carbon nanotubes has a large distribution density. The plurality of first carbon nanotubes are connected with each other and form a conductive network. In one embodiment, number of the first carbon nanotubes in 1 square micrometers is equal to or greater than 20. The number of carbon nanotubes in 1 square micrometers is defined as distribution density. The first carbon nanotube layer has a small film resistor and a great electric conductive property. In one embodiment, the first film resistor R_{s1} of the first carbon nanotube layer is smaller than or equal to 10 k Ω per square.

A diameter of first carbon nanotubes is smaller than about 10 nanometers. A length of first carbon nanotubes ranges from about 1 micrometer to about 2 millimeters. In one embodiment, the diameter of first carbon nanotubes is about 6 nanometers, the length of first carbon nanotubes ranges from about 5 micrometers to about 100 micrometers.

In one embodiment, a thickness of the first carbon nanotube layer is about 6 nanometers, the first film resistor R_{s1} of the first carbon nanotube layer is about 5 k Ω per square, a length of the gate electrode 120, the source electrode 150, and the drain electrode 160 is about 10 micrometers, a width of the gate electrode 120, the source electrode 150, and the drain electrode 160 is about 10 micrometers.

The semiconductor layer 140 can include a second carbon nanotube layer. Referring to FIG. 4, the second carbon nanotube layer includes a plurality of second carbon nanotubes joined by van der Waals attractive force. The plurality of second carbon nanotubes is single-walled carbon nanotubes and arranged disordered. The second carbon nanotube layer and the first carbon nanotube layer have different distribution density of carbon nanotubes. Number of the plurality of second carbon nanotubes in 1 per square micrometer is smaller than or equal to 1. The distribution density of the plurality of first carbon nanotubes is about 20 times that of the plurality of second carbon nanotubes. The second carbon nanotube layer has a larger film resistor than the first carbon nanotube layer. In one embodiment, the second film resistor R_{s2} of the second carbon nanotube layer is greater than or equal to 100 k Ω per square.

A diameter of second carbon nanotubes is smaller than about 5 nanometers. In one embodiment, the diameter of second carbon nanotubes is about 3 nanometers, a thickness of the second carbon nanotube layer is about 3 nanometers, and a length of the second carbon nanotubes ranges from about 5 micrometers to about 100 micrometers.

A direction in a surface of the semiconductor layer 140 from the source electrode 150 to the drain electrode 160 is defined as an X direction. A direction in the surface of the semiconductor layer 140 that substantially perpendicular to the X direction is defined as a Y direction. A direction that substantially perpendicular to the surface of the semiconductor layer 140 is defined as a Z direction. A length of the middle part 142 of the semiconductor layer 140 along the X direction is defined as L. A width of the middle part 142 of the semiconductor layer 140 along the Y direction is defined as W. A

resistance R of the middle part 142 of the semiconductor layer 140, the second film resistor R_{s2} of the second carbon nanotube layer, the length L of the middle part 142, and the width W of the middle part 142 satisfy following formula:

$$R = R_{s2} \frac{L}{W}$$

A ratio of the length L and the width W of the middle part 142 is greater than 1. The length L of the middle part 142 is greater than 5 micrometers. The width W of the middle part 142 is equal to or greater than 5 micrometers. In one embodiment, the length L of the middle part 142 is greater than or equal to 40 micrometers and smaller than or equal to 100 micrometers. The second film resistor R_{s2} of the second carbon nanotube layer is greater than or equal to 100 k Ω per square. The resistance R of the middle part 142 is greater than or equal to 100 k Ω . The electric conductivity property of the middle part 142 is between a conductor and an insulator. The middle part 142 has a semiconductor property. In one embodiment, the length L of the middle part 142 is about 40 micrometers, the width W of the middle part 142 is about 5 micrometers, and the second film resistor R_{s2} of the second carbon nanotube layer is about 330 k Ω per square per square.

Length of the first connecting part 144 and the second connecting part 146 along the X direction and the Y direction is arbitrary. In one embodiment, length along the Y direction of the first connecting part 144 and the second connecting part 146 is greater than the width along the Y direction of the middle part 142. In one embodiment, the length along the Y direction of the first connecting part 144 and the second connecting part 146 is about 10 micrometers, and the width along the X direction of the first connecting part 144 and the second connecting part 146 is about 5 micrometers.

The source electrode 150 and the drain electrode 160 are located on the two ends of the semiconductor layer 140 along the X direction. The first connecting part 144 is in contact with a part of the source electrode 150. The second connecting part 146 is in contact with a part of the drain electrode 160. Other part of the source electrode 150 and other part of the drain electrode 160 are exploded to connect with external route electrically (not shown). Because the thickness of the semiconductor layer 140 is small, the semiconductor layer 140, the source electrode 150 and the drain electrode 160 are located on a same surface. The semiconductor layer 140 can only include the middle part 142 with two ends in contact with and electrically connected to the source electrode 150 and the drain electrode 160. Because each of the semiconductor layer 140, the source electrode 150 and the drain electrode 160 includes carbon nanotubes, a great interface between the semiconductor layer 140 and the source electrode 150 or the drain electrode 160 is formed, therefore enhancing the property of the thin film transistor 10.

The material of the insulating layer 130 can be a rigid material such as aluminum oxide (Al_2O_3), silicon nitride (Si_3N_4), silicon dioxide (SiO_2), or a flexible material such as polyethylene terephthalate (PET), benzocyclobutenes (BCB), polyester or acrylic resins. A thickness of the insulating layer 130 can be in a range from about 10 nanometers to about 100 micrometers. In one embodiment, the material of the insulating layer 130 is Al_2O_3 , and the thickness of the insulating layer 130 is about 40 nanometers.

In use, the source electrode 150 is grounded. A voltage Vds is applied to the drain electrode 160. Another voltage Vg is applied on the gate electrode 120. The voltage Vg forming an

electric field in the channel. Accordingly, carriers exist in the channel near the gate electrode **120**. As the V_g increasing, a current is generated and flows through the channel. Thus, the source electrode **150** and the drain electrode **160** are electrically connected. Referring to FIG. 5, the thin film transistor **10** has high on/off ratio of current ($>10^4$) and electron mobility.

A method of making the thin film transistor is further provided. The method includes following steps:

Step (S1), providing an insulating substrate **110**;

Step (S2), forming a gate electrode **120** on the insulating substrate **110**, wherein the gate electrode **120** includes a first carbon nanotube layer with a first film resistor smaller than or equal to 10 k Ω per square;

Step (S3), forming an insulating layer **130** on the gate electrode **120**;

Step (S4), forming a source electrode **150** and a drain electrode **160** on the insulating layer **130**, wherein the source electrode **150** and the drain electrode **160** are spaced from each other, the source electrode **150** and the drain electrode **160** include a first carbon nanotube layer with a first film resistor smaller than or equal to 10 k Ω per square per square; and

Step (S5), forming a semiconductor layer **140** on the insulating layer **130**, wherein the semiconductor layer **140** is in contact with the source electrode **150** and the drain electrode **160**, and the semiconductor layer **140** includes a second carbon nanotube layer with a second film resistor greater than or equal to 100 k Ω per square per square.

In step (S1), the insulating substrate **110** can be rigid materials, such as glass, crystal, ceramic, diamond, and silicon, or flexible materials such as plastic or resin. In one embodiment, the material of the insulating substrate is polyethylene terephthalate. The insulating substrate **110** can be further hydrophilic treated.

In step (S2), the first carbon nanotube layer includes a plurality of first carbon nanotubes. The first carbon nanotube layer can be an integrity of the plurality of first carbon nanotubes arranged disordered. The method of forming the gate electrode **120** is as follows: Step (S21), providing a first substrate and pre-treating the first substrate;

Step (S22), depositing a first catalyst layer on a surface of the first substrate;

Step (S23), placing the first substrate with the first catalyst layer in a reactor, and inputting an inert gas to the reactor;

Step (S24), inputting a carbon source gas, and growing the first carbon nanotube layer in a stepped temperature manner via chemical vapor deposition; and

Step (S25), transferring the first carbon nanotube layer from the first substrate to the insulating substrate **110** and forming a gate electrode **120**.

In step (S21), the first substrate can be further hydrophilic treated for combining with the first catalyst layer better. In one embodiment, the first substrate is pre-treated by following steps: first, hydrophilic-treating the first substrate by hydrogen peroxide and ammonia water; second, treating the first substrate by an organic solvent. After treating by hydrogen peroxide and ammonia water, a surface of the first substrate has a plurality of hydroxyl groups combining with the organic solvent. The organic solvent can include (3-aminopropyl)-triethoxysilane (APTES) with amino group to fix the first catalyst layer.

In step (S22), the first catalyst layer includes ferritin, metal, such as iron, cobalt, nickel, or metal oxide. The first catalyst layer can be formed by electron beam evaporation or other electrochemical method. In one embodiment, the first catalyst layer is ferritin. The first catalyst layer is deposited on the first

substrate by following steps: firstly, a first ferritin solvent is obtained by mixing ferritin and water with a first volume ratio; secondly, immersing the first substrate into the first ferritin solvent for a first time. The first volume ratio of ferritin and water can be in a range from about 1:100 to about 1:20. The first time of immersion can be in a range from 20 minutes to 2 hours. In one embodiment, the first volume ratio of ferritin and water is about 1:50, and the first time of immersion is about 1 hour. Referring to FIG. 6, the image is taken from a region of a length of about 1 micrometer and a width of about 1 micrometer, the first catalyst layer includes a plurality of dense catalyst particles, and number of catalyst particles of the first catalyst layer in 1 square micrometers is greater than 800. Because the distribution density of catalyst particles of the first catalyst layer is large, the plurality of first carbon nanotubes has a large distribution density and forms an electric conductive network.

In step (S23), inputting the inert gas to the reactor is to make sure that environment of the reactor has no oxygen. The inert gas can be nitrogen or argon. In one embodiment, the inert gas is argon.

In step (S24), the carbon source gas can be methane, methanol, ethanol, ethylene, or acetylene. The stepped temperature manner is as follows: step (a), oxidizing a plurality of catalyst particles of the first catalyst layer in air atmosphere under a first temperature for 5 minutes to 30 minutes; step (b), reducing the plurality of catalyst particles in hydrogen or ammonia atmosphere under a second temperature for 5 minutes to 30 minutes; step (c), inputting the carbon source gas under a third temperature for a growing time and growing the plurality of first carbon nanotubes. The growing time of making the first carbon nanotube layer is in a range from about 20 minutes to about 2 hours. The first temperature is in a range from about 650 degrees centigrade to about 750 degrees centigrade. The second temperature is in a range from about 750 degrees centigrade to about 850 degrees centigrade. The third temperature is in a range from about 850 degrees centigrade to about 950 degrees centigrade. Number of single-walled carbon nanotube of the first carbon nanotube layer in 1 square micrometers is greater than 20. In one embodiment, the carbon source gas is a mixed gas of ethanol, methanol and methane with a carrier gas of hydrogen. A volume ratio of methanol and ethanol is in a range from about 1:1 to about 1:5. In one embodiment, the volume ratio of methanol and ethanol is about 1:3. A flowing rate of the carrier gas is in a range from about 50 standard-state cubic centimeter per minute (sccm) to about 200 sccm. A flowing rate of methane gas is in a range from about 50 sccm to about 200 sccm. In one embodiment, the flowing rate of the carrier gas is about 100 sccm, the flowing rate of methane gas is about 100 sccm, the stepped temperature manner includes: step (a) is under about 700 degrees centigrade for about 20 minutes, step (b) is under about 800 degrees centigrade for about 20 minutes, and step (c) is under the third temperature is about 900 degrees centigrade for about 1 hour, the first film resistor of the first carbon nanotube layer is about 5 k Ω per square per square, and a thickness of the first carbon nanotube layer is about 6 nanometers.

In step (S25), the first carbon nanotube layer is transferred as a whole. The first carbon nanotube layer can be transferred by a dry transferring method or a wet transferring method. The dry transferring method includes following steps: coating the first carbon nanotube layer by an adhesive belt; and detaching the adhesive belt via heating under a temperature from about 90 degrees centigrade to 150 degrees centigrade. In one embodiment, the adhesive belt is detached via heating

under about 120 degrees centigrade. The wet transferring method includes following steps:

(a1) coating the organic adhesive layer on the first carbon nanotube layer and solidifying the organic adhesive layer;

(b1) detaching the first single-walled carbon nanotube layer from the first substrate onto the organic adhesive layer via a reactive reagent;

(c1) placing the first carbon nanotube layer and the organic adhesive layer on the insulating substrate **110**; and

(d1) removing the organic adhesive layer by an organic solvent.

The material of the organic adhesive layer can be positive photoresist ZEP or polymethylmethacrylate (PMMA). The reactive reagent can react with the first substrate to separate the first carbon nanotube layer from the first substrate. The reactive reagent can be hydrogen fluoride, carbon fluoride, sodium hydroxide, or potassium hydroxide. In one embodiment, the organic adhesive layer is PMMA. The first carbon nanotube layer can maintain the original structure by the organic adhesive layer.

After transferring, the first carbon nanotube layer can be etched to form the gate electrode **120**. The method of etching the first carbon nanotube layer can be photolithography method, reactive ion etching method (RIE), or oxidation method. In one embodiment, etching the first carbon nanotube layer includes following steps:

(a2) forming a mask on a surface of the first carbon nanotube layer, wherein the mask is a hydrogen silsesquioxane layer;

(b2) etching part of the mask to obtain a mask with a pattern and exposing part of the first carbon nanotube layer;

(c2) removing the exposed first carbon nanotube layer via RIE method; and

(d2) removing the mask.

In step (S4), the insulating layer **130** can be formed via evaporating, sputtering, or atom layer depositing. In one embodiment, the insulating layer **130** is formed on a surface of the gate electrode **120** away from the insulating substrate **110** via evaporating, the gate electrode **120** is covered by the insulating layer **130** totally, material of the insulating layer **130** is aluminum oxide, and a thickness of the insulating layer **130** is about 40 nanometers.

In step (S4), forming the source electrode **150** and the drain electrode **160** includes following steps: forming the first carbon nanotube layer on a surface of the insulating layer **130**, and etching the first carbon nanotube layer. Etching the first carbon nanotube layer is same as that of step (S3). In one embodiment, the length along the Y direction of the source electrode **150** and the drain electrode **160** is about 10 micrometers, and the width along the X direction of the source electrode **150** and the drain electrode **160** is about 5 micrometers.

In step (S5), making the second carbon nanotube layer is simple as making the first carbon nanotube layer of step (S2). The difference of step (S5) and step (S2) is that the volume ratio of ferritin and water and the growing time. The volume ratio of ferritin and water of making the second carbon nanotube layer is in a range from about 1:8000 to about 1:1000. The growing time of making the second carbon nanotube layer is in a range from about 30 seconds to about 5 minutes. Number of the plurality of second carbon nanotubes in 1 square micrometers is smaller than 1. Therefore, the second carbon nanotube layer has a semi-conductive property. Referring to FIG. 7, the image is taken from a region of a length of about 1 micrometer and a width of about 1 micrometer, the second catalyst layer includes a plurality of second catalyst particles, and number of second catalyst particles in 1 square

micrometers is about 60. In one embodiment, the volume ratio of ferritin and water of making the second carbon nanotube layer is about 1:2000, the growing time is about 1 minute, and second film resistor of the second carbon nanotube layer is about 330 k Ω per square per square, and a thickness of the second carbon nanotube layer is about 3 nanometers.

Part of the second carbon nanotube layer can further be etched to obtain the semiconductor layer **140**. The method of etching part of the second carbon nanotube layer is same as that of etching the first carbon nanotube layer of step (S4). The semiconductor layer **140** is formed by selectively etching part of the second carbon nanotube layer between the source electrode **150** and the drain electrode **160**. A ratio of the length and the width of the middle part **142** is greater than 1. The length of the channel is greater than 5 micrometers. The width of the middle part **142** is equal to or greater than 5 micrometers. The middle part **142** has great semiconductor property.

The second carbon nanotube layer cannot be etched so that a large first connecting part **144** and a large second connecting part **146** are formed. The large first connecting part **144** and large second connecting part **146** can be in firmly contact with the source electrode **150** and the drain electrode **160** respectively.

In one embodiment, the length L of the middle part **142** is about 40 micrometers, the width W of the middle part **142** is about 5 micrometers, the length along the Y direction of the first connecting part **144** and the second connecting part **146** is about 10 micrometers, and the width along the X direction of the first connecting part **144** and the second connecting part **146** is about 5 micrometers.

In the method for making the thin film transistor **10**, because the distribution density of the plurality of second carbon nanotubes is smaller than that of the plurality of first carbon nanotubes, the step (S4) of forming the source electrode **150** and the drain electrode **160** are before the step (S8) of forming the semiconductor layer **140**, in order to avoid the second carbon nanotube layer being etched excessively. In one embodiment, the source electrode **150** and the drain electrode **160** are formed at first, then the second carbon nanotube layer is placed on the source electrode **150** and the drain electrode **160**, part of the second carbon nanotube layer is etched on the insulating layer **13**, and the channel is obtained.

Referring to FIG. 8, a thin film transistor **10** of another embodiment includes a gate electrode **120**, an insulating layer **130**, a semiconductor layer **140**, a source electrode **150**, and a drain electrode **160**. The source electrode **150** and the drain electrode **160** are spaced from each other. The semiconductor layer **140** is electrically connected to the source electrode **150** and the drain electrode **160**. The gate electrode **120** is insulated from the semiconductor layer **140**, the source electrode **150**, and the drain electrode **160** through the insulating layer **130**. The thin film transistor **20** is positioned on a surface of an insulating substrate **110**.

The structure of the thin film transistor **20** is similar with that of the thin film transistor **10**. The difference between the thin film transistor **20** and the thin film transistor **10** is that the source electrode **150** and the drain electrode **160** are located on the insulating substrate **110**, the semiconductor layer **140** is located on the insulating substrate **110** and extends onto the source electrode **150** and the drain electrode **160**, and the insulating layer **130** covers the semiconductor layer **140**, the source electrode **150**, and the drain electrode **160**. The gate electrode **120** is located on a surface of the insulating layer **130** away from the insulating substrate **110**. The semiconduc-

tor layer includes a middle part **142**. The middle part **142** is between the source electrode **150** and the drain electrode **160**.

The thin film transistor has following advantages. Firstly, the material of the semiconductor layer **140**, the source electrode **150**, and the drain electrode **160** is carbon nanotubes, the interface resistance between the semiconductor layer **140** and the source electrode **150** or the drain electrode **160** is reduced, and on/off ratio of current and electron mobility of the thin film transistor is enhanced. Secondly, the diameter of the single-walled carbon nanotube is less than 10 nanometers, the thickness of the first carbon nanotube layer and the second carbon nanotube layer is small, thus the light transmittance of the thin film transistor is high.

Depending on the embodiments, certain of the steps described may be removed, others may be added, and the sequence of steps may be altered. It is also to be understood that the description and the claims drawn to a method may include some indication in reference to certain steps. However, the indication used is only to be viewed for identification purposes and not as a suggestion as to an order for the steps.

It is to be understood, however, that even though numerous characteristics and advantages of the present embodiments have been set forth in the foregoing description, together with details of the structures and functions of the embodiments, the disclosure is illustrative only, and changes may be made in detail, especially in matters of shape, size, and arrangement of parts within the principles of the disclosure.

What is claimed is:

1. A method of making a thin film transistor, the method comprising:

providing an insulating substrate;

forming a gate electrode on the insulating substrate, wherein the gate electrode comprises a first carbon nanotube layer with a first film resistor that is smaller than or equal to 10 k Ω per square;

applying an insulating layer on the gate electrode;

forming a source electrode and a drain electrode on the insulating layer, wherein the source electrode and the drain electrode are spaced from each other, and each of the source electrode and the drain electrode comprises a third carbon nanotube layer, and a film resistor of the third carbon nanotube is smaller than or equal to 10 k Ω per square;

forming a semiconductor layer on the insulating layer, wherein the semiconductor layer is in contact with the source electrode and the drain electrode, and the semiconductor layer comprises a second carbon nanotube layer with a second film resistor greater than or equal to 100 k Ω per square;

exposing a part of the insulating layer to form a channel by etching a portion of the second carbon nanotube layer that is between the source electrode and the drain electrode, wherein a ratio of a length and a width of the channel is greater than 1.

2. The method of claim 1, wherein the providing the first carbon nanotube layer is same as the providing the third carbon nanotube layer, and the providing the first carbon nanotube layer comprises:

depositing a first catalyst layer on a first substrate;

locating the first substrate with the first catalyst layer in a reactor; and

inputting a carbon source gas, and growing the first carbon nanotube layer via chemical vapor deposition;

wherein the depositing the first catalyst layer on the first substrate comprises:

mixing ferritin and water with a volume ratio of ferritin and water to obtain a first ferritin solvent, wherein the volume ratio of ferritin and water ranges from about 1:100 to about 1:20; and

immersing the first substrate into the first ferritin solvent.

3. The method of claim 2, wherein the first catalyst layer comprises a plurality of dense catalyst particles, and number of catalyst particles of the first catalyst layer in 1 square micrometers is greater than 800.

4. The method of claim 2, wherein the providing the first carbon nanotube layer further comprises pretreating the first substrate before depositing the first catalyst layer on the first substrate, and the pretreating the first substrate comprises:

hydrophilic-treating the first substrate by hydrogen peroxide and ammonia water; and

treating the first substrate by an organic solvent.

5. The method of claim 2, wherein the growing the first carbon nanotube layer comprises:

oxidizing a plurality of catalyst particles of the first catalyst layer in air atmosphere;

reducing the plurality of catalyst particles in hydrogen or ammonia atmosphere; and

inputting the carbon source gas under about 850 degrees centigrade to about 950 degrees for a growing time to grow single-walled carbon nanotubes, wherein the growing time ranges from about 20 minutes to about 2 hours.

6. The method of claim 5, wherein the providing the first carbon nanotube layer further comprises transferring the first carbon nanotube layer to the insulating substrate and etching the first carbon nanotube layer to form the gate electrode after growing the first carbon nanotube layer.

7. The method of claim 6, wherein transferring the first carbon nanotube layer comprises:

coating a organic adhesive layer on the first carbon nanotube layer and solidifying the organic adhesive layer;

detaching the first carbon nanotube layer from the first substrate onto the organic adhesive layer via a reactive reagent;

placing the first carbon nanotube layer and the organic adhesive layer on the insulating substrate; and

removing the organic adhesive layer by an organic solvent.

8. The method of claim 6, wherein etching the first carbon nanotube layer comprises:

forming a mask on a surface of the first carbon nanotube layer, wherein the mask is a hydrogen silsesquioxane layer;

exposing part of the first carbon nanotube layer by etching the mask to obtain an exposed portion;

removing the exposed portion via RIE method; and removing the mask.

9. The method of claim 5, wherein the carbon source gas is mixed gas of ethanol, methanol and methane with a carrier gas of hydrogen, a volume ratio of methanol and ethanol is in a range from about 1:1 to 1:5.

10. The method of claim 9, wherein a flowing rate of the carrier gas of hydrogen is in a range from about 50 sccm to 200 sccm, and a flowing rate of methane gas is in a range from 50 sccm to 200 sccm.

11. The method of claim 1, wherein the providing the second carbon nanotube layer comprises:

depositing a second catalyst layer on a second substrate;

locating the second substrate with the second catalyst layer in a reactor; and inputting a carbon source gas, and growing the second carbon nanotube layer in a stepped temperature manner via chemical vapor deposition;

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wherein the deposition the second catalyst layer on the second substrate comprises:
 mixing ferritin and water with a volume ratio of ferritin and water to obtain a second ferritin solvent, wherein the volume ratio of ferritin and water ranges from about 1:8000 to about 1:1000; and
 immersing the second substrate into the second ferritin solvent.

12. The method of claim **11**, wherein the growing the second carbon nanotube layer in the stepped temperature manner comprises:

oxidizing a plurality of catalyst particles of the second catalyst layer in air atmosphere;
 reducing the plurality of catalyst particles in hydrogen or ammonia atmosphere; and
 inputting the carbon source gas under about 850 degrees centigrade to about 950 degrees for a growing time to

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grow single-walled carbon nanotubes, wherein the growing time ranges from about 30 seconds to about 5 minutes.

13. The method of claim **12**, wherein a oxidizing time of the oxidizing the plurality of catalyst particles of the second catalyst layer is in a range from 5 minutes to 30 minutes, and a time of reducing the plurality of catalyst particles in hydrogen or ammonia atmosphere is in a range from 5 minutes to 30 minutes.

14. The method of claim **12**, wherein a oxidizing temperature of the oxidizing the plurality of catalyst particles of the second catalyst layer is in a range from 650 degrees centigrade to 750 degrees centigrade, and a temperature of reducing the plurality of catalyst particles in hydrogen or ammonia atmosphere is in a range from 750 degrees centigrade to 850 degrees centigrade.

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